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Ecoacoustic monitoring of lake sturgeon (*Acipenser fulvescens*) spawning and its relation to anthropogenic noise

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Abstract

Lake sturgeon (*Acipenser fulvescens*) are endangered in the Laurentian Great Lakes with increasing binational efforts to establish spawning grounds to aid restoration. While SCUBA surveys can document spawning activity, these are labour-intensive and may disrupt spawning. We used passive acoustic monitoring to quantify spawning sounds of lake sturgeon as a first step to developing remote sensing of sturgeon spawning grounds. *Acipenser* sp. are known to make a variety of sounds including, "thunders" (aka drums), which have been documented in *A. fulvescens* during spawning. We quantified drums from a known spawning bed. We recorded 5 different potential sturgeon sounds but only quantified drums as a marker for spawning activity. Drums were low frequency with average frequency peaks at 40 and 92 Hz and a rapid drop-off thereafter. There was no relationship between calling activity and water temperature but calling activity increased as the summer progressed. Call production was most active from 0600 to 1500 h with little calling activity during nighttime recordings. The presence of low frequency boat sounds did correlate with a reduction in maximum calling rate so it is possible that commercial shipping may disrupt sturgeon communication, but more research is necessary to separate correlational from causative effects. These recordings represent a promising approach to map sturgeon spawning activity and show the potential effect of human activity on communication in this threatened species.

KEYWORDS
assessment, boat noise, fish, passive acoustic

1 | INTRODUCTION

Lake sturgeon were historically abundant across North America but overfishing (Harkness & Dymond, 1961; Peterson et al., 2007) and habitat fragmentation (Dieterman et al., 2011; Haxton & Findlay, 2008; Pollock et al., 2015) caused dramatic reductions in their distribution (Bruch et al., 2016). Increased conservation efforts in North America however are aiding lake sturgeon recovery and a significant factor in recovery has been artificial spawning substrates (Chalupnicki et al., 2011; Jackson et al., 2002). Lake sturgeon preferentially spawn over substrate consisting of larger rocks & cobble (Baril et al., 2018; Smith et al., 2017) and while current velocity does vary (Smith et al., 2017), a recent meta-analysis shows that they prefer to spawn in areas with a current high enough to keep substrates clear of sand and debris (Baril et al., 2018). One factor limiting recruitment of lake sturgeon may be the need for clean, hard, spawning substrates (Fischer et al., 2018; Pollock et al., 2015). Significant effort has been expended to provide artificial spawning areas (McLean et al., 2015) and placing hard substrates in traditional ranges has proven effective at attracting spawning fish and recruiting new juveniles to the population (Caswell et al., 2004; Fischer et al., 2018; Johnson et al., 2006). While the use of artificial reefs is encouraging, it can be difficult to quantify spawning activity in both natural and manmade habitats due to limitations on monitoring resources and, especially for natural spawning grounds, difficulty in identifying known spawning habitats (Pollock et al., 2015). It is thus imperative that we continue to identify practical methods for discovering spawning beds and monitoring progress of known spawning populations to better assess spawning activity in this important species.

One cost-effective method for monitoring spawning activity in both marine and freshwater environments is Passive Acoustic Monitoring (PAM; e.g. Desjonquères et al., 2020; Luczkovich et al., 2008; Rountree et al., 2006). The PAM technique, as the name implies, entails deploying hydrophones, either singularly or in arrays, for extended periods and recording all sounds in the vicinity of the hydrophone. Since sound typically travels further underwater than in air, dependent on water depth (Rogers & Cox, 1988), useful recordings can be obtained a considerable distance from a spawning site and the sounds can be collected without disturbing natural behaviours of the species of interest. For PAM to be a successful monitoring tool, species must make either purposeful acoustic emissions or incidental, but species-specific, sounds while spawning. This technique has been used on a large number of fish species that have been shown to incorporate sounds into their spawning behaviour (e.g. Bolgan et al., 2018; Locasio & Mann 2011; Luczkovich et al., 2008; Rowell et al., 2017; Schärer et al., 2012; Straight et al., 2014) and has even been used to identify previously unknown spawning aggregations (Johnson et al., 2017; Picciulin et al., 2013; Wall et al., 2013). While PAM does require a species make species-specific sounds while spawning, a large number of fish species have been shown to incorporate sounds in their spawning behaviour (Kasumyan, 2009; Ladich, 2004) making this a promising monitoring tool. The use of PAM can also be worthwhile for examining effects of anthropogenic disturbances on natural spawning activity; a growing problem of global concern (Nolet, 2017; Slabbekoorn et al., 2010). While PAM has been extensively used in marine habitats, it is less prevalent for freshwater monitoring; however, this use has been increasing in recent years (e.g. Desjonquères et al., 2015; Higgs & Humphrey, 2020; Linke et al., 2018; Rountree & Juanes, 2017) and shows great potential for extended monitoring of spawning activity.

The purpose of the current study was to use PAM to better characterize spawning sounds of lake sturgeon in their natural habitat and to test hypothesized influences of underwater noise as a disruptor of fish communication abilities (de Jong et al., 2018; Picciulin et al., 2012; Radford et al., 2014; Vasconcelos et al., 2007). Lake sturgeon possess a basal inner ear allowing them to hear frequencies of approximately 100–500 Hz (Lovell et al., 2005) a hearing range that overlaps the frequency often produced by larger shipping vessels that may be present at the reef monitored in this study (Haren, 2007; Kozaczka & Grelowska, 2011; Merchant et al., 2012). Lake sturgeon are known to make at least one characteristic sound while spawning (Bruch & Binkowski, 2002) and perhaps up to six different sounds (Bocast et al., 2014). While the presence of these sounds has been known by fisheries managers for many years (Priegel & Wirth, 1974, as cited in Bruch & Binkowski, 2002) the degree of variation in these signals remains unclear both during the spawning period and between fish within one spawning bout. Other sturgeon species have also been reported to produce sounds coincident with spawning (Johnston & Phillips, 2003; Tolstoganova, 1999) and those that have been adequately categorized (Johnston & Phillips, 2003) tend to have a low frequency peak (below 400 Hz) and a duration of approximately 200 ms. In addition, because lake sturgeon habitat restoration is occurring in frequently busy waterways (Johnson et al., 2006; Roseman et al., 2011), it is important to understand how anthropogenic noises may interact with spawning sounds — although work in some species has shown a reduction in spawning sounds coincident with boating activity (Picciulin et al., 2012; Vasconcelos et al., 2007), this might be species-dependent (Higgs & Humphrey, 2020). To properly use call production to monitor spawning of sturgeon as recommended in the past (Johnston & Phillips, 2003), and to better quantify the possible impacts of anthropogenic sounds on spawning (Nolet, 2017), it is first necessary to more fully characterize sounds emitted from natural spawning populations and test for any correlations with anthropogenic activity.

2 | METHODS

2.1 | Study site

Hydrophones were placed off of a private dock on Fighting Island, LaSalle Ontario (Latitude: 42°14′31.99″N, longitude: 83°6′47.27″W), immediately adjacent to an artificial Lake Sturgeon spawning reef constructed in 2003 (Roseman et al., 2011) and expanded in 2013. Spawning at this site had been suspected before the reef was constructed (Caswell et al., 2004) and active spawning has now been verified at the reef site every spring from April to June (Fischer et al., 2018; Roseman et al., 2011).

2.2 | Acoustic recording

Hydrophones were weighted with a concrete block, deployed in 3-5m of water, and tied securely to the dock to avoid movement while recording. For acoustic recordings one DSG-Ocean Integrated Recording Unit (Model LS1; Loggerhead Instruments; www.loggerhead.com) was deployed and replaced once per week from May 8 to June 28, 2014, corresponding to the known spawning time of lake sturgeon on the artificial reef habitat. Recordings had to be stopped at the end of June due to logistical constraints. The recorders were coupled with an integrated hydrophone with sensitivity = −180 dB re 1 V/μPa and a calibrated response frequency from 10 to 10,000 Hz. Recorders were programmed for continuous recording in 10 min file packets throughout the course of their deployment but only the first 3 min of each recording were analysed due to time constraints. The resultant .dsg files were converted to .wav format and all .wav files were visually analysed for potential sounds of interest. All potential sounds were listened to by trained observers to assess their similarities to known sturgeon reproductive calls (thunders or drums from Bocast et al., 2014; provided from the first author as a courtesy). Once all files were analysed a second, blind, observer went through all identified calls to verify their veracity.

2.3 | Acoustic analysis

Quantification of acoustic parameters of sturgeon sounds was accomplished with the software program Audacity (audacityteam.org). Files were visually analysed in waveform view for suspected sturgeon calls and then verified by ear to match known sound files as identified in Bocast et al. (2014) to resemble "thunder" (aka drums) spawning sounds. Sounds were identified as drums if they had multiple pulses and low frequency and sounded to the observer like thunder. Other sounds were noted but not included in this analysis if they did not sound like the known drumming calls to the observers. Sounds of interest could be easily identified for listening if they were at least 10 dB above the background noise in the visualized trace. The number of drums was quantified per hour of recording over the course of the hydrophone deployment. For frequency analysis, samples were analysed with a Hanning window and an FFT size of 16384. Each sound was quantified for the primary peak frequency (defined as largest peak in the FFT window), secondary frequency (the second-most powerful peak), the frequency cutoff (the frequency at which the relative power decreased by at least 20 dB) and the call duration. In addition, we also quantified the degree of boat noise present in the sound files and subdivided "boat" into low frequency (likely commercial freighters; Haren, 2007; Kozaczka & Grelowska, 2011; Merchant et al., 2012) and high frequency (likely recreational boats; Codarin et al., 2009) occurrences. Boat noises were also first identified from visual inspection of the traces and could be detected at the same 10 dB above background as the biological signals. The two types of boat noise were easily discernable by ear as the low frequency boat noise had a significant drop-off in energy beyond 100 Hz while the high frequency boat noise had a large amount of energy up to 10 kHz (Figure 1) Each type of boat noise was quantified in terms of the number of minutes each boat noise was present per hour of recording.

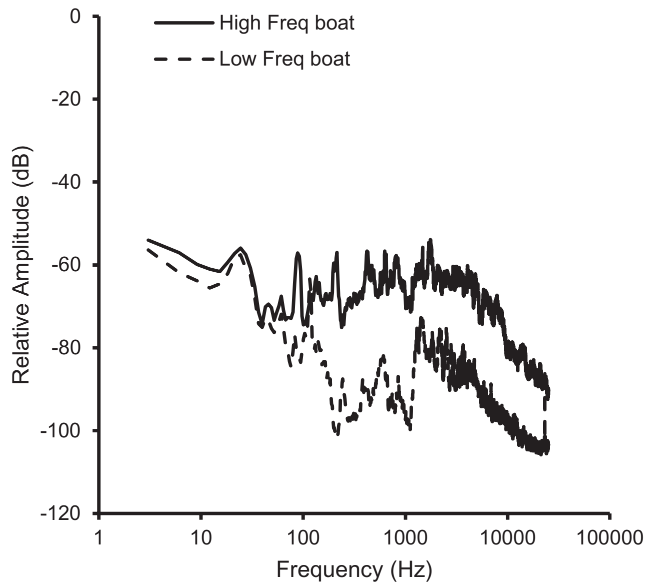

FIGURE 1 Power spectra (Hanning Window, FFT size = 16,384) of representative samples of high frequency and low frequency boat sounds recorded from the PAM hydrophone

2.4 | Statistical analysis

For the call characteristics — peak frequencies, cut-off frequency, and call duration — measures of central tendency were calculated to provide known ranges of these parameters for future identification of sturgeon spawning sounds in a field setting. Normality was assessed for all parameters using Q-Q plots and calculations of skewness and kurtosis. For all frequency measures data were normal (Table 1) so parameters were regressed, using a linear regression, against date of sampling to test whether there were changes in these call parameters during the spawning season. Duration was not normal (Table 1) so the relationship between call duration and sampling date was analysed by Kendall-Thiel regression. For the relationships between calling activity and time as well as calling activity and boat noise presence, statistical analyses were used to examine hypothesized drivers of sturgeon calling activity, with calling rate also being normal (Table 1). To identify peak calling periods, univariate ANOVA was used with time of day as main effect and number of calls/hr as the response variable with Tukey posthoc testing to identify differences between times in the significant ANOVA result. When visualizing changes in call rate with date there appeared to be a differential effect between early and later dates so a piecewise regression was run to first estimate breakpoints and then to examine the differential relationship between calling activity and date. To investigate the possible relationship between calling activity and water temperature, linear regression was used. Water temperature was provided by the United States Geological Service monitoring station 5 km downstream from the spawning bed (USGS 04166500 River Rouge at Detroit, MI; waterdata.usgs.gov). While the temperatures were not collected directly on the spawning bed, they do provide a good approximation of conditions experienced by the spawning animals. Finally, to examine a possible relationship between the presence of low-frequency or high-frequency boat noise impacting spawning sounds, curvilinear regression was used on the relationship of each of these separately with calling rate. All statistical analysis was done in R (version 4.0.3) using RStudio (version 1.4.1103, 2020). For all tests significance was set to $p < 0.05$.

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TABLE 1 Descriptive statistics of all measured call parameters

Metric	Dominant frequency (Hz)	Secondary frequency (Hz)	Frequency dropoff (Hz)	Call duration (s)	Maximum call rate (#/h)
Mean	40.9	92.1	114.2	1.5	7.8
SD	34.5	48.5	75.0	2.0	1.1
Min	0.8	17.0	34.0	0.3	0
Max	175	215.0	114.2	19.4	15
Skewness	0.87	0.35	0.84	3.2	0.81
Kurtosis	−0.009	0.43	−0.26	11.3	−1.03

3 | RESULTS

A total of 376 calls were collected that could be definitively identified as lake sturgeon drums (Figure 2). Calling activity started slowly, with between 0 and 15 calls/day on most days from May 8 to 26 (Figure 3). After May 31 calling rate increased with date, reaching a peak of 47 calls/day by June 11. As a result of the clear inflection point in the data, two separate regressions were run, one before and one after May 31. In the first set of samples, there was not a significant change in calling rate over time (regression: $y = 10.18 - 0.52x$; $r^2 = 0.12$, $p = 0.20$) while in the second set of samples there was a significant increase in calling rate over time (regression: $y = -31.9 + 2.59x$; $r^2 = 0.44$; $p = 0.02$).

3.1 | Frequency analysis

The recorded sturgeon calls had two obvious peak frequencies (Figure 2b,c), with some variation between individual calls. The first peak frequency was at 40.9 ± 1.6 (mean ± 1 SE) Hz but there was a significant decrease in the frequency of the first peak frequency (Figure 4a) with date of recording (regression $y = 110.9 - 3.29x$; $r^2 = 0.71$; $p \leq 0.001$), except for days 15–17 when a separate event may be occurring. The secondary peak frequency occurred at 92.1 ± 4.2 Hz and there was again a significant negative relationship (Figure 4b) between frequency output and date for this call characteristic (regression: $y = 154.95 - 4.48x$; $r^2 = 0.607$; $p < 0.001$).

The power of the recorded calls was concentrated on the low frequency end of the spectrum, with a sharp drop in frequency output occurring on average after 114.2 (±3.5) Hz, although some calls did have significant power up to 450 Hz. There was again a negative relationship between the drop-off frequency and date of recording (regression: $y = 218.2 - 5.68x$; $r^2 = 0.56$, $p < 0.001$; Figure 4c) with again a secondary peak occurring between days 14 and 17.

3.2 | Temporal analysis

The duration of the calls averaged 1.4 (±0.09) s, with the maximum duration of any call being 20 s and the majority of all calls being less than 5 s in duration (Figure 5). Again, there was a significant negative relationship between call duration and date of recording (regression:

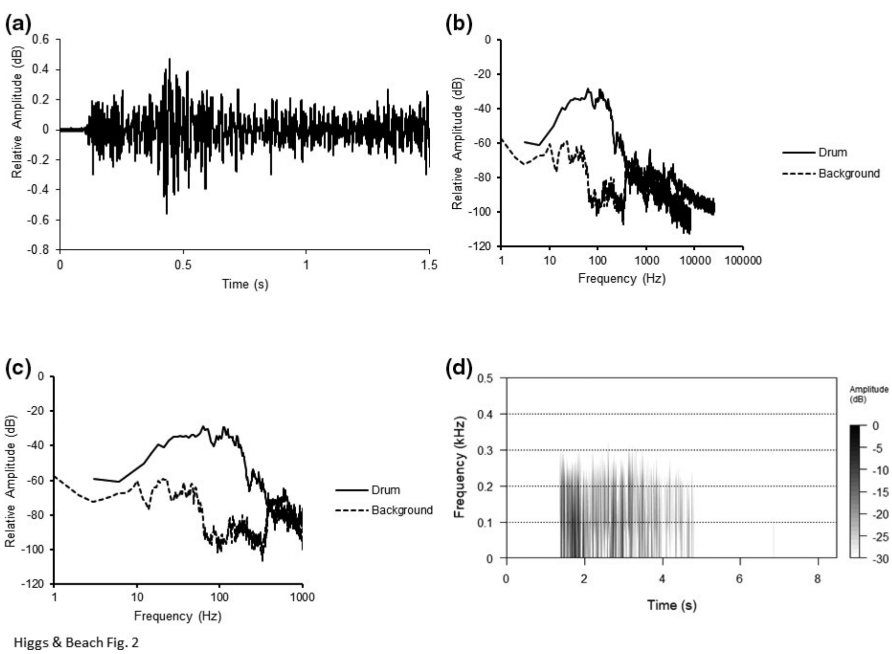

FIGURE 2 Waveform view (a) of a typical Lake Sturgeon drum call recorded from the Detroit River as well as the power output of the call up to 10 kHz (b) and the output over the main frequency range embedded in the call (c) as well as the spectral view of the recorded call (d)

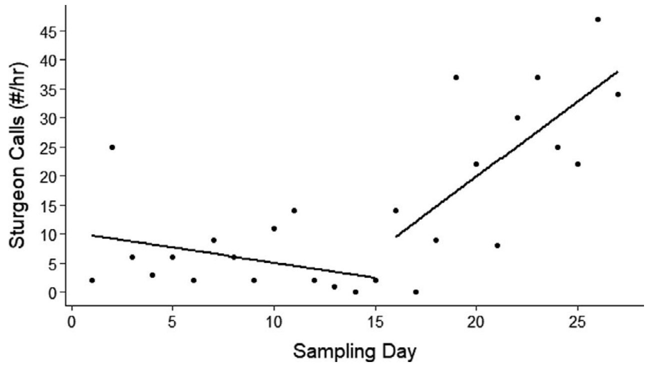

FIGURE 3 Piecewise regression analysis of changes in the calling rate of Lake Sturgeon with sampling day of acoustic recording. For ease of visualization "Date" has been replaced with "Sampling day". Sampling day 1 is May 8 2014, day 10 is May 19 and day 20 is June 4

$y = 2.07 - 0.08x$; $r^2 = 0.31$, $p < 0.001$), although the largest effect seemed to be a decrease in the variation of call duration over time (Figure 5).

Across all dates tested there was a significant effect of time of day on calling rate ($F_{23,648} = 5.02$, $p < 0.001$). Fish started calling at 6:00 a.m., stopped calling at 8:00 a.m. and then called again from 9:00 a.m. to 3:00 p.m. before decreasing again to essentially 0 at 4:00 p.m. and staying quiet the rest of the night (Figure 6). While the highest average calling rate was just over 2 calls/h at 6:00 a.m. and 7:00 a.m. (Figure 6), individual days got as high as 15 calls/h at our recording site.

There was no significant relationship between the number of recorded calls and temperature throughout the range of this study (Regression: $y = -13.73 + 1.9$; $r^2 = 0.09$ and $F_{1,25} = 2.44$, $p = 0.13$). There did appear to be an expanded range of calling behaviour with temperature, recording as many as 40 calls/day at higher temperatures (Figure 7) but the pattern was not consistent enough to drive a relationship between these two parameters.

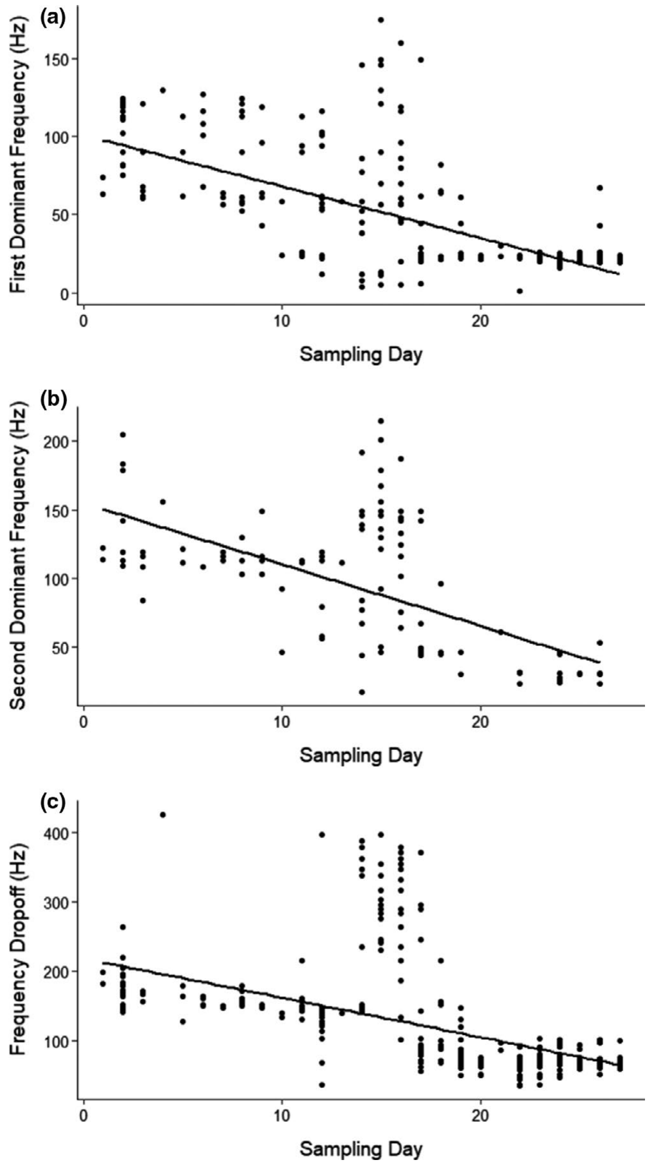

FIGURE 4 Changes in (a) first peak, (b) second peak and (c) drop-off frequency from all recorded calls with sampling day of acoustic recording. Sampling day as in Figure 2

3.3 | Anthropogenic effects

Examination of the effects of the presence of high-frequency boat calls on calling rate showed a significant but weak relationship between boating activity and sturgeon calling ($r^2 = 0.015$, $F_{3,655} = 3.25$, $p = 0.021$) but the large number of instances of recordings with no calls (Figure 8a) may have biased the relationship. We also examined the possible effect of high frequency boat sounds on maximum calling and there was a marginally insignificant ($r^2 = 0.45$, $F_{3,12} = 3.32$, $p = 0.057$) effect of the presence of high-frequency boat sounds on maximal calling rate (Figure 8b) but the calls tended to increase with boat sound presence.

Examination of the effects of the presence of low-frequency boat noise on calling rate showed no apparent relationship between boating activity and sturgeon calling ($r^2 = 0.005$, $F_{3,654} = 1.19$, $p = 0.312$) but again the large number of instances of recordings with no calls (Figure 8c) may have biased the relationship therefore we also examined the possible effect of low frequency boat sounds on maximum calling. There was a strong negative relationship ($r^2 = 0.90$, $F_{3,11} = 33.53$, $p > 0.001$) between maximum calling rate and the presence of low frequency boat sounds, dropping to near zero when the presence of boats reached approximately 8 min per hour of recording (Figure 8d).

4 | DISCUSSION

The sounds we detected were both visually and aurally similar to those previously reported from spawning lake sturgeon (Bocast et al., 2014) and that, coupled with the location just upstream of a known spawning bed, makes us confident that our drum sounds

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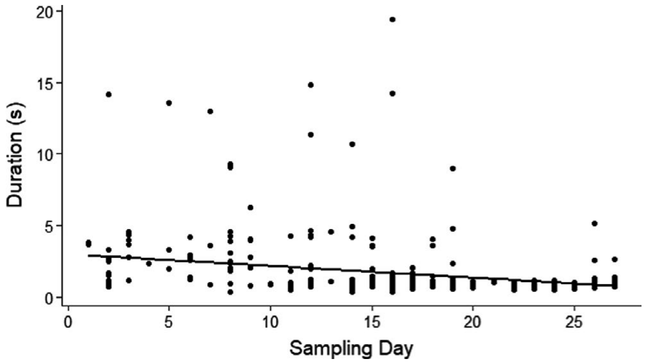

FIGURE 5 Changes in the duration of individual Lake Sturgeon calls over sampling day. Sampling day as in Figure 2

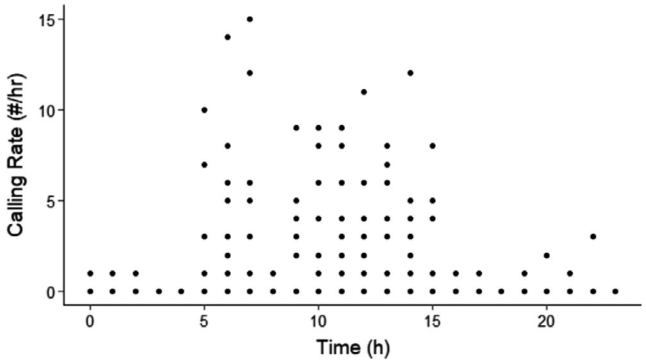

FIGURE 6 Diurnal changes in the calling rate of Lake Sturgeon calls across all sampling days. Each data point represents the calling rate for a given day at that time point, although many points overlap

were an accurate representation of spawning activity of this species. We showed a change in variance structure of the calls of this population in terms of both frequency and temporal characteristics and our analysis showed a clear diurnal periodicity to this vocalization activity. These data therefore represent a launch point for future efforts to identify spawning aggregations of lake sturgeon using PAM as well as provide more information on the possible changes in spawning structure of these populations.

4.1 | Identification of sturgeon calls

One drawback to using PAM for monitoring species without a visual site line is being certain you are detecting the species of interest. This is especially true for fish species as there is still an inadequate library of fish calls available, with little effort to characterize individual soniferous species in a field setting. We are confident we are recording lake sturgeon in the current work for several reasons. The reef we were recording from was specifically constructed to support lake sturgeon spawning (Caswell et al., 2004) and eggs have been collected from the reef during our sampling window (Fischer et al., 2018; Roseman et al., 2011). In local waters, only a few fish species—freshwater drum; *Aplodintus grunniens* (Rountree & Juanes, 2017), Centrarchidae (Ballantyne & Colgan, 1978; Gerald, 1971), some Siluriformes (Fine et al., 1997; Kaatz et al., 2010)—are known to make calls however none of these have calls that resemble those characterized here. Bocast et al. (2014) have characterized sounds in the field from mating lake sturgeon and the drum calls they identified are similar in frequency content to those reported here. Bocast et al. (2014) did report somewhat lower maximum frequencies than we found but they were recording right next to the spawning population while our recordings were further from the spawning bed, perhaps losing some of the low frequency content due to absorption by the riverbed. Johnston and Phillips (2003) recorded two different species of sturgeon in the lab, and our drum call is very similar in frequency structure to their "moan" calls emitted during a spawning event. Finally, Tolstoganova (1999) did report a much higher frequency range from spiny sturgeon (*Acipenser nudiventris*); up to 9.3 kHz while most of our energy was cut off below 500 Hz but there was energy up to 10 kHz in the drum call. We also recorded multiple other sound types with significant higher frequency components but chose not to quantify those because we were less certain of their origin. This last represents a significant problem with using PAM to characterize spawning activity of fish as we are still behind terrestrial researchers in our library of categorized fish calls.

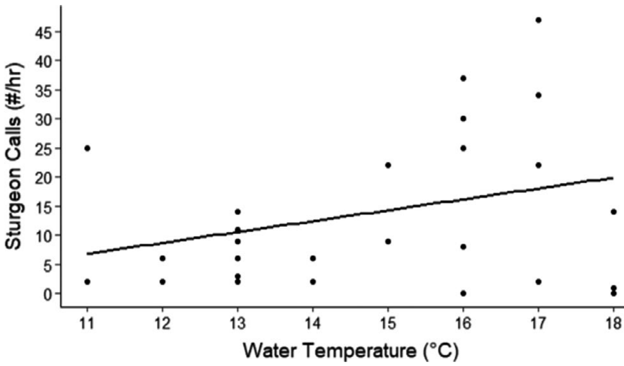

FIGURE 7 The relationship between water temperature and calling rate, in number of calls/hr of Lake Sturgeon

4.2 | Frequency effects

The statistically significant decreases in frequency bandwidth as the spawning season progressed was interesting. While there was an increase in water temperature over the course of our recording session, there was no association between water temperature and calling behaviour so it is unlikely that the frequency changes are due to temperature. Johnston and Phillips (2003) found a negative association between fish size and peak frequency in pallid sturgeon (*Scaphirhynchus albus*) and shovelnose sturgeon, (*S. platorynchus*) and in other species, the frequency content of mating calls does decrease with fish size (reviewed in Amorim et al., 2015). The clear differences in frequency content seen on days 15–17 (May 30–June 1) do suggest a change in the calling dynamics on the spawning

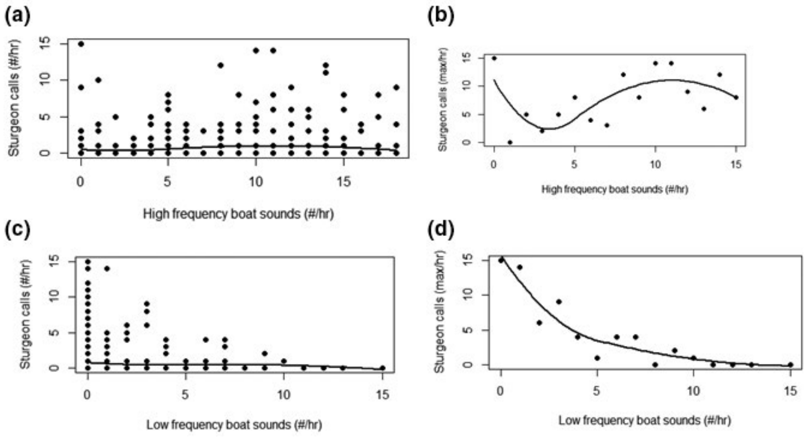

FIGURE 8 The relationship between the presence of high frequency boat sounds and the (a) overall and (b) maximum calling rate of Lake Sturgeon as well as the relationship between the presence of low frequency boat sounds and the (c) overall and (d) maximum calling rate of Lake Sturgeon

bed, perhaps due to new individuals reaching the spawning site. In white sturgeon (*Acipenser transmontanus*), males arrive on spawning beds up to two weeks before females (Paragamian & Kruse, 2001) so changes in frequency and duration seen here may also represent changes in calling motivation as females arrive on site. While not possible in the present study, it would be interesting to track time of arrival of lake sturgeon on the spawning bed to investigate possible size-dependence of arrival time of spawning individuals.

4.3 | Temporal patterns

While we found no significant relationship between calling rate and water temperature, there did seem to be an increase in the variation of call rates after a temperature of about 14°C — fitting a pattern seen in other studies of lake sturgeon. Lake sturgeon typically spawn between 11°C and 21°C (Bruch & Binkowski, 2002; Chiotti et al., 2008; LaHaye et al., 1992) and the entire temperature range seen in our study was 11–18°C — reinforcing our view that we captured the peak spawning time in our system. Males may arrive on spawning beds first — when temperature is lower (Bruch & Binkowski, 2002) — so the increased variation we saw with temperature may again be due to increased effort by spawning males. Calling behaviour is known to increase in other fish species with temperature (Connaughton et al., 2002; Kever et al., 2015; Ladich, 2018) and can correlate with overall activity in a PAM context (McWilliam et al., 2017; Wall et al., 2013).

The diurnal periodicity we found where fish were calling from 6:00 a.m. to 3:00 p.m. is difficult to compare with other work simply due to the paucity of diurnal calling information in lake sturgeon and in sturgeon in general. Bruch and Binkowski (2002) report approximately equal spawning intensity of lake sturgeon during the day and at night in a shallow river system while we heard no spawning sounds at night in our deeper system. Sulak et al. (2002) show that gulf sturgeon (*Acipenser oxyrinchus desotoi*) jump out of the water as a possible communication signal with peaks from 2:00 a.m. to 2:00 p.m., decreasing at 4:00 p.m. but then increasing again back up from 6:00 p.m. to 9:00 p.m. Peterson et al. (2007) noted there is little known about courtship behaviour of lake sturgeon but that several males will surround a female and smack her with their tails, suggesting there may be a visual component to males locating females (Bruch & Binkowski, 2002). At the current suspected spawning site, lake sturgeon are spawning in approximately 10 m of water with approximately 1 m of visibility (Caswell et al., 2004). If visual communication is an important part of lake sturgeon spawning behaviour, our acoustic recordings would be expected to be highest during daylight hours, dropping to nothing as visibility decreases overnight. However, more work needs to be conducted on direct observations of spawning behaviours in these murkier waters to ascertain the importance of visual signaling in this behaviour.

4.4 | Anthropogenic effects

The mixed effects we saw on boat noise and calling rate may be due to the different frequency components of different boat types. The higher frequency boat noises we recorded, similar to those seen emitted from recreational boats (Codarin et al., 2009), were correlated with an increase in maximum calling rate so it seems clear that they did not disrupt vocalization behaviour in our system. The high-frequency boat recordings had main energy components from 300 Hz up to 10 kHz while the putative sturgeon drum calls we recorded had their predominant energy below 100 Hz; so there was little overlap between these two sound sources. The low frequency noise, likely emitted from commercial freighters (Haren, 2007; Kozaczka & Grelowska, 2011; Merchant et al., 2012), had peak energy also below 100 Hz so it is possible that the sturgeon ceased calling as these boats passed overhead. Traffic noise disrupts the calling behaviour of blacktail shiner (*Cyprinella venusta*; Holt & Johnston, 2015) and boat noise can mask reception of calling sounds in Lusitanian toadfish (*Halobatrachus didactylus*; Vasconcelos et al., 2007) so it is possible that similar effects were seen in our present study. Anthropogenic noise is understudied in freshwater environments but it is clear that it can be a known stressor for fish (Mickle & Higgs, 2018). Sturgeon hearing is most sensitive below 300 Hz and they may be essentially deaf to any frequencies above 500 Hz (Lovell et al., 2005) which may make them especially vulnerable/sensitive to noise of the commercial freighters passing overhead and unable to hear the higher frequency recreational boats. There is increasing interest in possible effects of shipping activity on fish behaviour and survival (e.g., Haren, 2007; Neenan et al., 2016; Slabbekoorn et al., 2010) and while our data are not conclusive they do suggest more studies should be conducted to quantify possible effects of shipping during spawning of this threatened family of fish.

4.5 | Conclusions

The current study demonstrates the clear potential of using PAM to monitor lake sturgeon spawning activity and we would argue its use could be expanded to track other suspected sturgeon spawning locations. While our study used long-term acoustic deployments it would be of benefit to take shorter recordings over multiple sites along the length of the Detroit River corridor to map out spawning distributions more fully, and this work could be readily expanded to other suspected spawning habitats. While the field of fish acoustics is currently lacking clear automated recording software to definitely characterize species calls, many species like lake sturgeon do have characteristic calls that can be clearly differentiated from other local inhabitants. More attention should also be paid to the possible role of noise from larger ships on calling activity as it is possible that increased shipping could disrupt spawning vocalizations, and perhaps spawning activity, but more research must be conducted here to more clearly define this possible risk.

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DATA AVAILABILITY STATEMENT

All data and a sample of sturgeon sounds used in this study are available at dataDryad.org (https://doi.org/10.5061/dryad.9kd51c5j1).

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